Impact of Environmental Factors on Energy Efficiency of Room Air Conditioners in India

Neha Dhingra, Dr. Archana Walia, P K Mukherjee

CLASP

Abstract

Room Air Conditioners (RAC) dominate the Air Conditioning (AC) space cooling market comprising almost 40% of total cooling energy consumption in 2017-2018. Though RAC penetration in households in India is only 8% currently, rising incomes, urbanization and increasing cooling degree-days are expected to raise RAC ownership to 40% in 2037-38. This would cause a significant increase in power and peak load demand, environmental impacts, and greenhouse gas (GHG) emissions. Energy efficiency policies for appliances are one of the most cost effective methods to reduce electricity consumption. India's Bureau of Energy Efficiency (BEE) initiated a labeling program for RACs in 2006, and subsequently revised the program periodically to increase efficiency and establish performance in terms of the Indian Seasonal Energy Efficiency Ratio (ISEER) based on climate conditions. The energy efficiency of an RAC is based on performance tests at standard rated conditions. However, under actual operating conditions, the RAC is exposed to several adverse climatic conditions such as polluted ambient and saline conditions around coastal areas which can impact energy performance. There is little information or data available in the public domain regarding the potential impacts due to such environmental conditions. A study of the impact of short-term environmental impacts such as salinity, dust, and humidity on energy efficiency of an RAC were measured under simulated environmental conditions. This paper presents the methodology along with key findings and forward looking research in assessing the impact of external environmental conditions.

Keywords: Environmental factors, Indian Seasonal Energy Efficiency Ratio, Energy performance

Introduction

The AC market in India is largely dominated by RACs, which comprise approximately 40% of total cooling energy consumption in 2017-2018, with a forecasted increase to 50% by 2037-38[1]. The annual sales of RACs in India have increased rapidly in the last 10 years, from 0.3 million in 2007 to 7.6 million in 2017.[2] These trends have resulted in a significant increase in electricity demand and energy consumption in both the commercial and residential sectors. While Indian household RAC penetration is only 8% currently, rising incomes, urbanization and increasing cooling degree-days are expected to increase RAC ownership to 40% by 2037-38.[3] This would require a significant increase in peak and base power generation capacity and increase GHG emissions.

Air conditioning can substantially increase the electricity consumption of a household – typically, a 1.5-ton capacity AC[4] consumes about 1900 Watts of power equivalent to operating around 30 ceiling fans, which have been the traditional cooling appliance in India. However, the electricity demand from RACs can be reduced by increasing equipment efficiency. Energy efficiency policies for RACs are one of the most cost effective methods to reduce electricity consumption. In order to promote energy conservation and efficient use of energy, Government of India launched Energy Conservation Act in 2001 and established the BEE, a statutory body under Ministry of Power, for administration and

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[1] India Cooling Action Plan, March 2019

[2] [Solving the Global Cooling Challenge: How to Counter the Climate Threat from Room Air Conditioners]

[3] India Cooling Action Plan, March 2019

[4] 1 ton is equivalent to 18000 Btu or 18991 kJ

implementation of the Act in 2002.[5] BEE launched a Standards and Labeling (S&L) program to promote appliance and equipment efficiency in 2006, and brought RAC under the voluntary labeling program.[6] Currently, the labeling program for RACs is mandatory and includes both fixed and variable capacity (inverter) units.

Since 2018, the efficiency of a RAC in India is defined in terms of the Indian Seasonal Energy Efficiency Ratio (ISEER), which is the ratio of the cooling seasonal total load (CSTL) (in Watt hour) to cooling seasonal energy consumption (CSEC) (in Watt hour).This improved star rating methodology factors in the variance in temperature across the various climatic zones in India and annual operating hours.

For the labeling program, the energy efficiency of a RAC is tested under standard rated conditions in the test laboratory as per the Indian National Standard. However, ACs work under real life conditions, which are different from the standard rated conditions simulated in a test laboratory. In real operating environment, an AC is exposed to adverse climatic conditions such as polluted ambient (dust, vehicular and industrial pollution) and saline conditions around coastal areas. This may result in changes in efficiency due to one or more of the following:

a) Reduced air circulation through heat exchanger,
b) Increased power consumption,
c) Longer operating times required to achieve desired cooling set points,
d) Higher compressor failure rates due to condenser blockage causing higher condensing temperatures and refrigerant pressures,
e) Increased refrigerant leakage to atmosphere leading to higher global warming potential, and
f) Reduced effective useful life of equipment.

Considering the growing demand for RACs and their contribution to energy consumption, the in situ energy performance of the product must be tested to ensure performance is not impacted by adverse environmental conditions. There is very little information or data available in the public domain of any significant impact of such environmental factors. Therefore, this preliminary study was conducted to understand and measure the impact of short-term environmental factors on RAC energy efficiency performance.

Objective

The key objective of the study was to assess the impact of long-term environmental factors such as salinity, dust, temperature and humidity on energy efficiency of a RAC by exposing them to short-term environmental conditions simulated in the test laboratory. This report does not address differences between short-term tests and performance tests of units with long-term environmental exposures.

The findings of the study may inform consumers, policy makers and manufacturers of any likely impact of the short-term environmental exposure on energy efficiency of RACs. However, the study will need to extended for a longer duration to provide information regarding long term exposure to adverse environmental conditions. Accordingly, it would help to perform additional tests of units with long-term environmental exposures such as 4 or 5 years of adverse environmental conditions and identify potential solutions to improve quality, reduce operating and maintenance costs, and save energy.

Approach and Methodology

The study focused on RACs, accounting for about 60-70% of space cooling in India[7]. The scope of the study was limited to un-ducted single split and unitary/window units including fixed and variable speed compressors with up to 11 kW cooling capacity. The study included the following steps:

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[5] http://www.beestarlabel.com/

[6] https://powermin.nic.in/en/content/energy-efficiency

[7] India Cooling Action Plan, March 2019

- Preparation of a representative sampling plan comprising of the following:
    a. Major brands available in the Indian market. The manufacturers' names have been kept confidential, but ensuring representation of all major brands.
    b. Categories (unitary/window and split) and type (variable and fixed type)
    c. Representative capacity of ACs sold in India (i.e., 5.27 kW or 1.5 TR (tons of refrigeration)[8]
    d. Different type of heat exchangers
- Identification of relevant national/international test standard for the environmental and energy performance testing of RACs
- Identification of a nationally accredited test laboratory to conduct energy performance and environmental testing
- Following a stepwise approach for testing:
    a) Conduct testing for cooling capacity and power consumption to establish the baseline efficiency
    b) Subject samples to the different short-term environmental conditions (such as corrosive, dusty and saline) as per the relevant national/international standards
    c) Conduct performance tests again and assess change from baseline due to short-term tests
    d) Analyze the test results to compare cooling capacity, power consumption and ISEER based on short-term environmental test conditions
    e) Determine if short-term tests are consistent with performance tests of units with long-term environmental exposures

Test Results and Analysis

Sample Selection

A random sample consisting of major brands, type and technology of RACs, different star rating bands (represented by 3-,4- and 5-star), types of heat exchanger and most sold star rating was prepared as shown in table 1 below:

Table 1: RAC Sampling Plan

S. No.	Type of test	Type of AC	Heat Exchanger	No of units
1	Dust test	Window	Copper	2
		Split (fixed speed)	Copper	2
		Split (Variable speed)	Aluminum	2
2	Salt mist test	Window	Copper	2
		Split (fixed speed)	Copper	2
		Split (Variable speed)	Aluminum	2
3	Composite temperature/humidity cycle test	Window	Copper	2
		Split (fixed speed)	Copper	2
			Aluminum	2
Total number of samples				**18**

[8] One ton of cooling is defined as heat energy removed from one short ton of water (2,000 pounds or 907.1847 kg) to produce one ton of ice at 32°F (0°C) in 24 hours. Energy required for phase change of liquid water at 32°F (0°C) into solid ice at 32°F is referred to as heat of fusion equal to 144 Btu/lb times 2,000 lbs of water or 288,000 Btu of energy over 24 hour period or 12,000 Btu/hour to make one ton of ice in one day. British thermal unit (Btu) is heat required to raise temperature of one pound (0.454 kg) of water one °F (0.556°C). Btu is equivalent to 1055.06 joules or 251.997 calories.

National/International Test Standards

Identification of Environmental test standards

An analysis of national environmental test standards was conducted and the following Indian test standards were identified:

- IS 9000 part XII for dust test - This standard provides test procedure for the dust test on electronic and electrical items. The objective of this test is to determine the suitability of electronic and electrical items for use and/or storage under dust laden atmosphere.

- IS 9000 part XI as per procedure 3 for salt mist test - This standard deals with the determination of the corrosive effects of salt atmospheres on electronic and electrical items. The objective of this test is to determine the suitability of electronic and electrical items when used or stored under salt laden atmospheres. This test is intended mainly for the evaluation, the quality and uniformity of protective coatings.

- IS 9000 part VI (10 cycles) Composite temperature/humidity cyclic test - This standard deals with a composite temperature/humidity cyclic (moisture resistance) test procedure. The objective of this test is to determine in an accelerated manner the resistance of items to the deteriorative effects of high temperature/humidity and cold conditions.

Identification of Energy performance test standards

The Indian test standards defined in BEE's labeling program for RACs were identified for efficiency testing:

- IS 1391 part 1 for unitary ACs
- IS 1391 part 2 for split ACs

Variable speed ACs were also tested using IS 1391 at full load only. The part load performance testing for variable speed RACs was not implemented.

The performance testing was performed using balanced ambient room-type calorimeter to measure cooling capacity and power consumption, in order to calculate the Indian seasonal energy efficiency ratio.

Selection of an accredited test laboratory to conduct energy efficiency and environmental testing

To select a nationally accredited independent test laboratory for efficiency and environmental testing, quotations were requested from all major test labs in India that have AC efficiency testing infrastructure in place. Sierra Aircon was selected to undertake the study based on a combined evaluation of the technical and financial proposals. Sierra Aircon partnered with SGS India Ltd. lab for environmental testing.

Test results

The samples were procured as per the plan in Table 1 and shipped to Sierra Aircon Pvt Ltd. The samples were provided a unique Unit ID to mask the brand name and for traceability. All samples were first tested to measure energy performance to establish a baseline. The samples were then subjected to environmental tests discussed above. After environmental testing, the samples were tested again for energy performance to assess any changes as a result of short-term exposure to environmental conditions.

Table 2 provides the performance and energy efficiency test results for both pre and post short-term environmental testing and the resultant variation in ISEER (as percentage) for all the samples.

Table 2: Summary of RAC Pre and Post Performance Test Results

S. No.	Environmental test	Type of AC	Heat Exchanger type	Pre Environmental test results			Post Environmental test results			Percentage drop between post and pre environmental test results		
				Total cooling capacity (W)	Total Power Input (W)	ISEER	Total cooling capacity (W)	Total Power Input (W)	ISEER	Total Cooling capacity	Power input	ISEER
1	Composite humidity test	Window	Copper	4937	1602.9	3.08	4817	1586.2	3.04	-2.43	-1.04	-1.30
2				4944	1601.2	3.09	4888	1585.9	3.08	-1.13	-0.96	-0.32
3		Fixed split	Copper	5159	1465.7	3.52	5153	1453.5	3.55	-0.12	-0.83	0.85
4				4925	1430.4	3.44	4834	1412.8	3.42	-1.85	-1.23	-0.58
5			Aluminum	4840	1456.7	3.32	4804	1452.6	3.31	-0.74	-0.28	-0.30
6				5016	1510.5	3.32	5005	1505.9	3.32	-0.22	-0.30	0
Average percentage drop from composite humidity test										**-1.08**	**-0.77**	**-0.28**
7	Dust test	Window	Copper	5143	1515.2	3.39	5014	1506	3.33	-2.51	-0.61	-1.77
8				5127	1512.5	3.39	5073	1493.8	3.4	-1.05	-1.24	0.29
9		Fixed split	Copper	4935	1419.2	3.48	4963	1430	3.47	0.57	0.76	-0.29
10				5098	1417.1	3.6	4937	1409	3.5	-3.16	-0.57	-2.78
11		Variable split	Aluminum	5786	2250.1	2.57	5594	2136.9	2.62	-3.32	-5.03	1.95
12				5183	1797.3	2.88	5143	1772.9	2.9	-0.77	-1.36	0.69
Average percentage drop from dust test										**-1.70**	**-1.34**	**-0.32**
13	Salt mist	Window	Copper	5191	1625.3	3.19	5165	1614.6	3.19	-0.50	-0.66	0
14				5096	1597.7	3.19	5047	1606.4	3.14	-0.96	0.54	-1.57
15		Fixed split	Copper	5248	1412.3	3.72	5220	1400.7	3.72	-0.53	-0.82	0
16				5295	1403.4	3.77	5232	1392.2	3.76	-1.19	-0.8	-0.27
17		Variable split	Aluminum	5579	1721.7	3.24	5562	1714.2	3.24	-0.30	-0.44	0
18				5473	1708.6	3.2	5468	1704.8	3.21	-0.09	-0.22	0.31
Average percentage drop from salt mist test										**-0.6**	**-0.4**	**-0.26**
19	Combined environmental tests	Fixed split	Copper	4925	1430.4	3.44	4844	1416.7	3.42	-1.64	-0.96	-0.58
20			Aluminum	5016	1510.5	3.32	4826	1457	3.31	-3.79	-3.54	-0.30
Average percentage drop from combined environmental tests										**-2.72**	**-2.25**	**-0.44**
Average percentage drop for all the samples										**0.98**	**-1.28**	**-0.30**

The percentage variation in the cooling capacity, power consumption and ISEER resulting from post and pre-environmental testing for all types of ACs are shown graphically in Figures 1, 2 and 3 respectively.

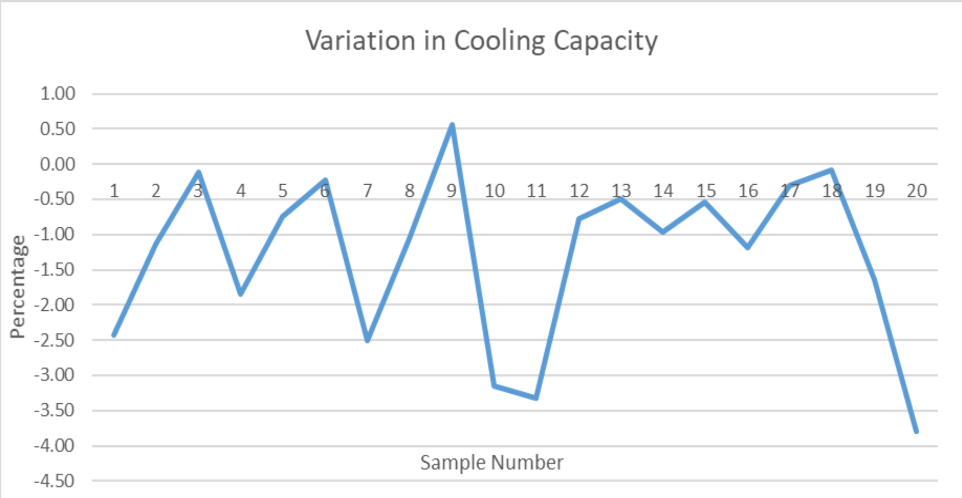

Figure 1: Cooling Capacity Variation from Pre and Post Environmental Tests

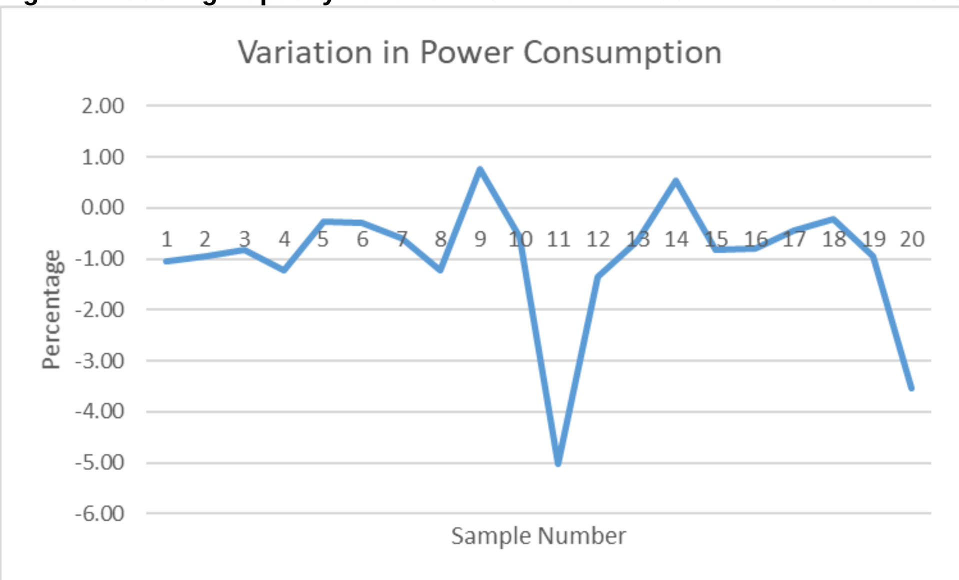

Figure 2: Power Consumption Variation from Pre and Post Environmental Tests

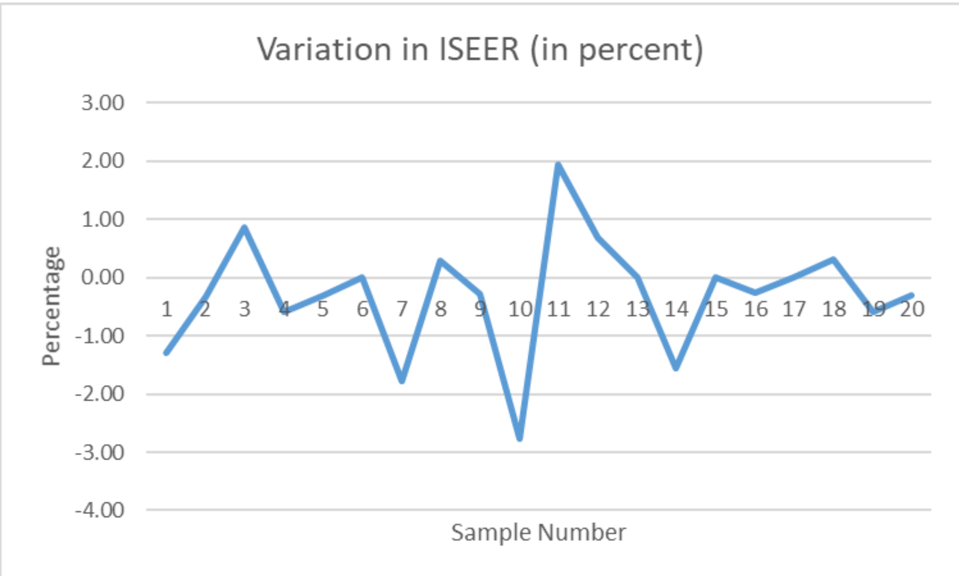

Figure 3: ISEER Variation from Pre and Post Environmental Tests

The key observations from the analysis of test results are:

- Reduced cooling capacity ranged from -3.79% to 0.57%, with an average of -1.28%.
- Reduced power ranged from -5.03% to 0.76%, with an average of 0.98%.
- Reduced ISEER ranged from -2.78% to 1.95%, with an average of -0.30%.

All these variation in the values are insignificant and within the tolerance limits prescribed in BEE's labeling schedule for all ACs (window, fixed and variable split).

Test results as per the type of environmental test

The results were further analysed to understand the impact of a specific environmental test t i.e., composite humidity, dust, salt mist test and combined environmental tests (sequential exposure) on energy performance. These trends are reflected graphically in figures 4 to 7 below:

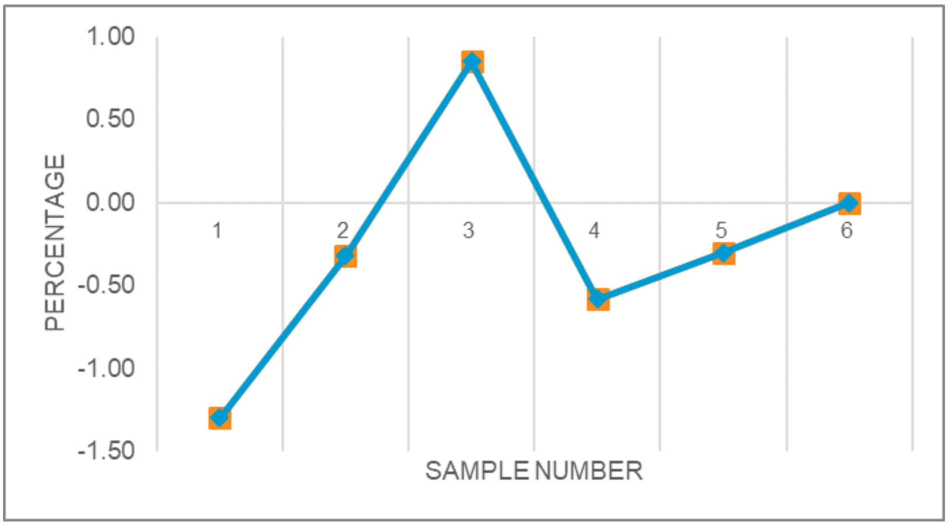

Figure 4: ISEER Variation from Composite Humidity Environmental Tests

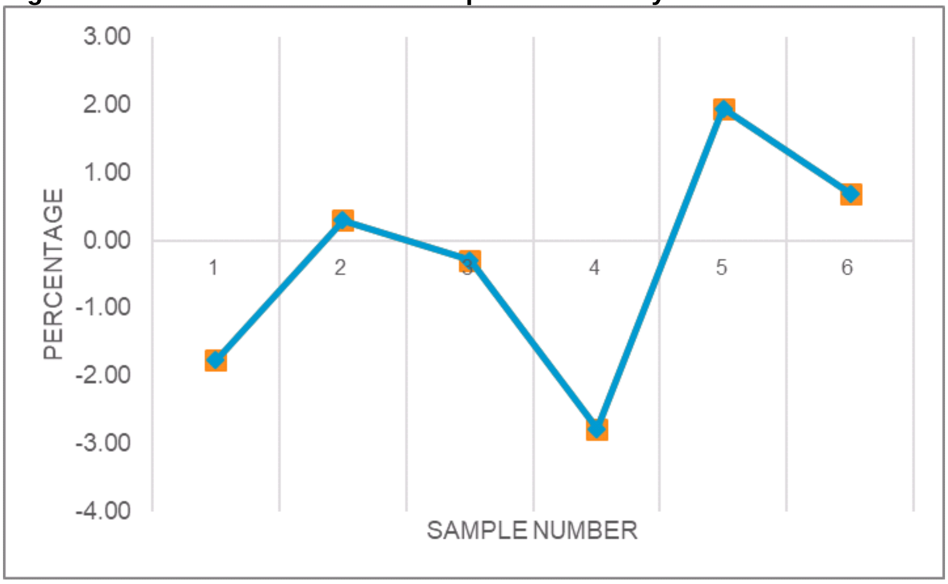

Figure 5: ISEER Variation from Dust Environmental Tests

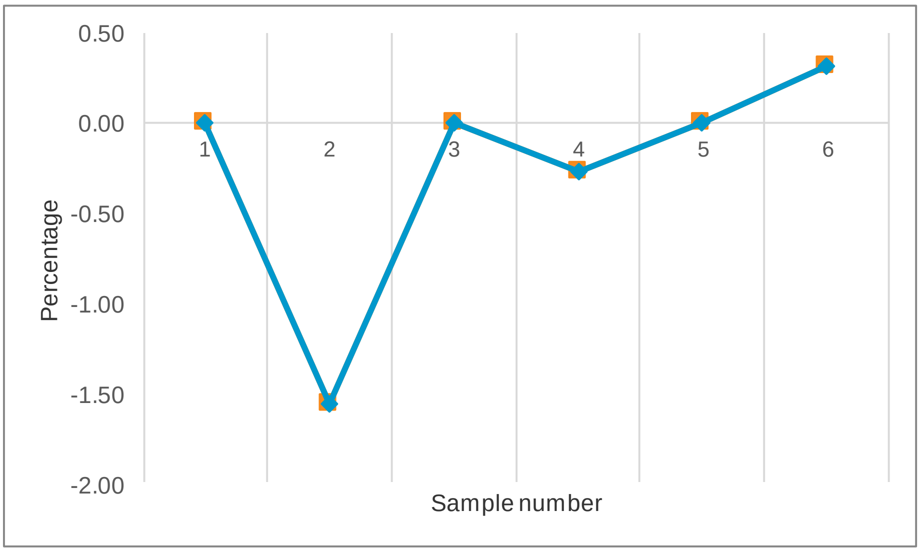

Figure 6: ISEER Variation from Salt Mist Environmental Tests

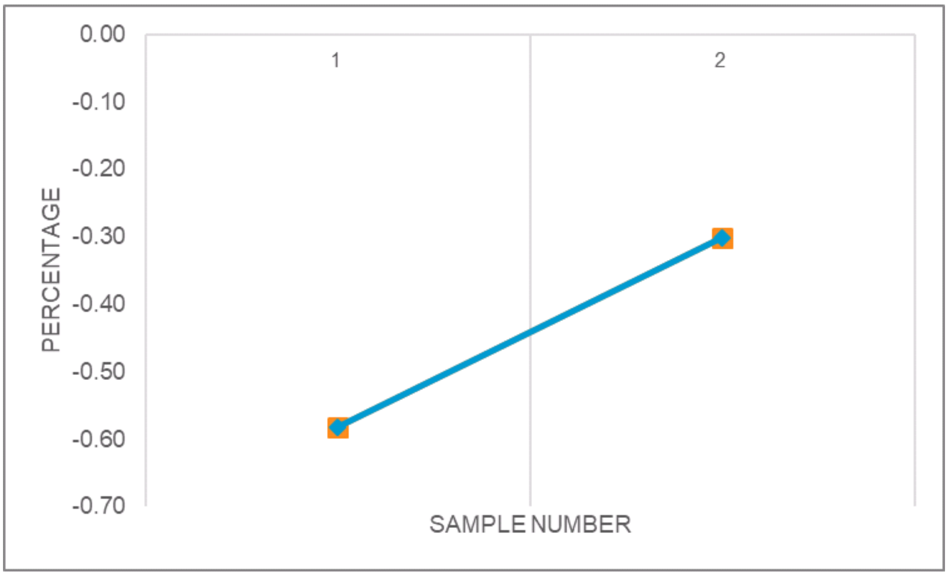

Figure 7: ISEER Variation from All Environmental Tests with Sequential Short-Term Exposures

The analysis of test results indicate that none of the environmental conditions individually or the combined effect when exposed sequentially had any significant effect on the energy performance of ACs. Minor variations observed with cooling capacity and power consumption were within prescribed tolerance limits due to short-term environmental exposure.

Test results as per the type of heat exchanger material

The results were further analysed to understand the impact of the short-term environmental tests on the basis of the type of heat exchanger material (Aluminum and Copper). The variation in ISEER post and pre environmental testing is shown in figure 8 and 9 below-

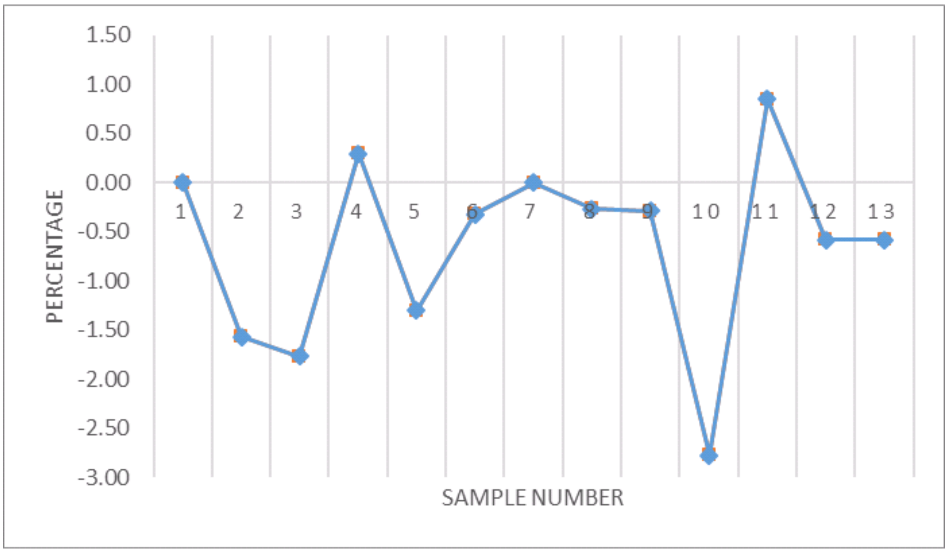

Figure 8: ISEER Variation for ACs with Copper heat exchanger

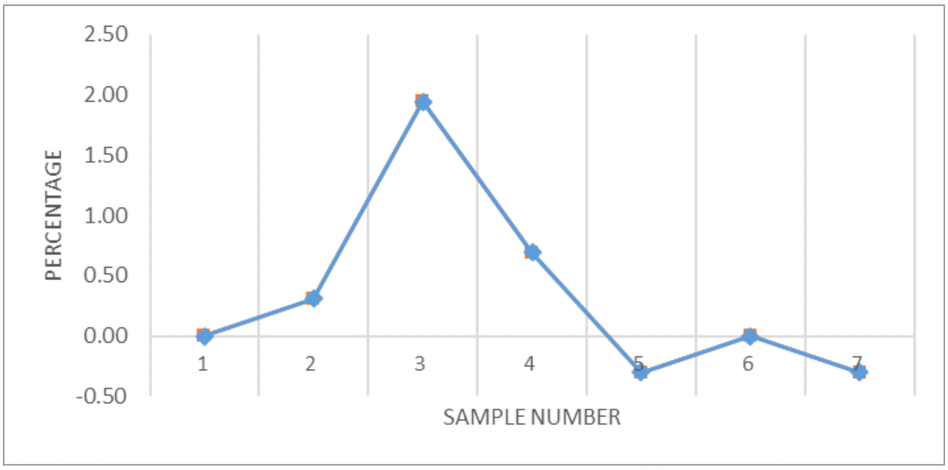

Figure 9: ISEER Variation for ACs with Aluminum heat exchanger

The analysis of test results indicate that none of the short-term environmental conditions individually or the combined effect when exposed sequentially had any significant effect on the energy performance of ACs with either Aluminum or Copper type heat exchanger.

Conclusion

Based on the test results, the performance of the RACs sold in India is not affected by short-term exposure to environmental conditions (dust, salt mist, and composite humidity) simulated in the test laboratory irrespective of the type of AC or the type of heat exchanger or the type of tests.

This could possibly, be due to some quality measures taken by manufacturers that safeguard against environmental factors resulting in little or no measurable impact on energy efficiency under standard testing conditions. These may include, but not limited to:

- Sound manufacturing technique that prevented galvanic corrosion of heat exchanger coils and thereby not affecting the life of aluminum fin and copper tube bonding and able to withstand the salt mist exposure.
- Thickness of the copper tube and aluminum fin is sufficient to take care of environmental exposure.

- The e-coating provided on heat exchanger surface gives adequate protection to withstand environmental exposure.

It should be noted that the conclusions are based on short term exposure by simulating environmental conditions in the test lab. However, in future, the study can be further expanded to expose the samples to salt mist test for a prolonged duration i.e. as defined in relevant Indian standard for heat exchanger to assess the impact of prolonged exposure to saline conditions on energy performance of RAC. In addition, samples from the field across various climatic conditions can be tested to assess the impact on energy performance in real life situation over a select period.

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